

A DIRECT COMPARISON BETWEEN EUV CORONAL FLUX AND HELIUM RESONANCE LINE PHOTON FLUX FROM SOHO/CDS DATA

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ABSTRACT

In the wealth of EUV spectroscopic and imaging data gathered by the SOHO and TRACE missions, a prominent role is played by the helium resonance emission. For example, He I lines are among the most intense features in CDS/NIS spectra, while the EIT 304 waveband (dominated by He II emission) is routinely employed to map the structure of the solar chromosphere and transition region. However, no 'standard' model has emerged so far that is able to interpret observed He spectra/images to a satisfactory degree of self-consistency.

Recent research on the problem of the formation of the solar helium spectrum tends to rule out a dominant role of coronal radiation in exciting He resonance lines. However, while evidence for this result is strong, it is based on indirect tests. Here we present a preliminary assessment of this issue based on a more direct approach, which involves a measure with CDS/GIS of the photoionizing EUV radiation. This measure can be directly compared with the observed flux in the main He I and He II resonance lines observed with CDS/NIS2.

Key words: EUV; radiative transfer; helium.

diffuse appearance is expected if the excitation source is in the corona. Similarly, the fact that coronal hole boundaries appear rather sharp in the helium lines is not readily accounted for by the PR model. Up to date, the problem of whether, and to what extent the PR mechanism is effective in the solar atmosphere, can be regarded as still unsolved.

One possible approach to test the role of coronal radiation in the formation of helium lines is to compare the photoionization rates with the relevant collisional excitation rates. For example, Jordan et al. (1993) have shown how the He II $\lambda 304$ line, the analogue of H I Ly α , is dominated by collisions in the quiet Sun. The result, however, is valid if the formation temperature is above 5×10^4 K. On the other hand, if the PR mechanism is valid, the formation temperature would be considerably lower, the region of formation being essentially determined by the hydrogen and helium density stratification in the upper chromosphere.

Other indirect tests have been devised in the specific case of He I (Andretta & Jones, 1997). In particular, it is possible to exploit the different conditions of formation of singlet and triplet lines. Tests on a comparison between the first He I resonance line at 584 Å and the strongest triplet line, at 10830 Å (Andretta et al. 1999), once more indicate that the PR mechanism is not dominant in the quiet Sun.

1. INTRODUCTION

The formation of the helium spectrum is a long-standing problem in solar physics. Yet, some of the most prominent features in the extreme ultraviolet are produced by that element. One proposed mechanism (Hirayama 1971; Zirin 1975) explains the observed intensities as the result of photoionization of both helium ions by coronal radiation followed by cascade recombinations. This process, often referred to as the "PR mechanism", is consistent with the decrease of He I and He II intensities observed in coronal holes. On the other hand, helium spectroheliograms generally show the typical structures seen in chromospheric and transition region lines, whereas a more

2. THE APPROACH: AN IDEALIZED EXAMPLE

Using a more direct approach, one can consider the case of a cool atmosphere illuminated by photoionizing radiation. For simplicity we consider a simple two-level plus continuum model atom, which is also the only absorber at the relevant wavelengths. The photon flux, Φ , in a spectral feature due to the transition between levels i and j (either a continuum or a line), is defined as:

$$\Phi_{ij} = \int_{4\pi} d\Omega \, \bar{n} \int_{\Delta\lambda_{ij}} d\lambda \, \frac{\lambda}{hc} I_{\lambda} ; \quad (1)$$

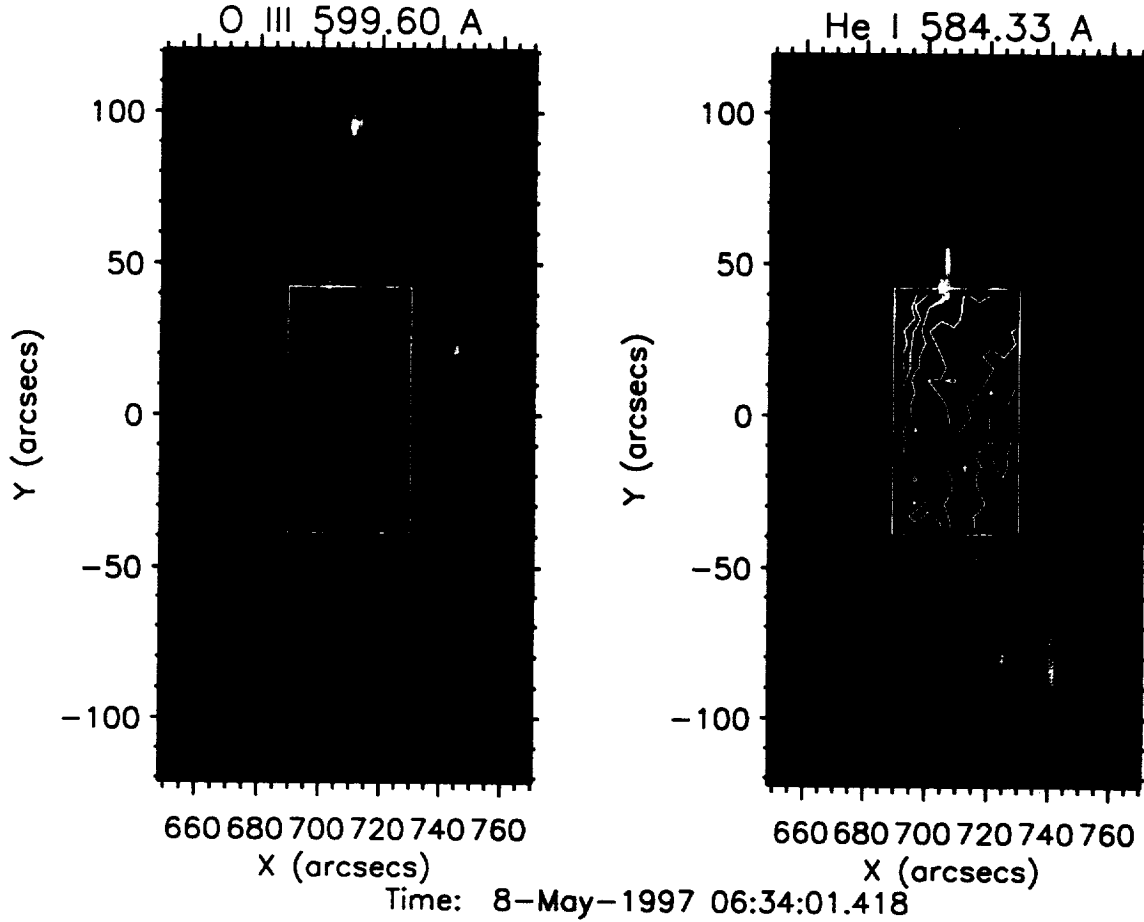


Figure 1. The quiet Sun area in the field of view of the CDS Normal Incidence Spectrograph (NIS) on May 8, 1997, in two lines observed in NIS wavelength band 2. The field of view of the Grazing Incidence Spectrograph (GIS) is also shown, together with intensity isopleths of the Fe XV 284 Å line.

where I_λ is the specific intensity in the direction \vec{n} . The integration is performed over all directions and over the wavelength band, $\Delta\lambda_{ij}$, appropriate for the spectral feature.

The equation of transfer of the photon fluxes in the resonance line and continuum of the model atom becomes:

$$\vec{\nabla} \Phi_{13} = -n_1 R_{13} + n_3 R_{31} \quad (2)$$

$$\vec{\nabla} \Phi_{12} = -n_1 R_{12} + n_2 R_{21} \quad (3)$$

In these equations, R denotes radiative rates, and n are population densities for levels 1 (ground state), 2 (excited level) and 3 (continuum). If statistical equilibrium holds, and collisional excitation and ionization rates are negligible, one then obtains:

$$\vec{\nabla}(\Phi_{12} + \Phi_{13}) = 0 \quad (4)$$

Deep in the atmosphere, the total photon density, and therefore the flux, are negligible. Thus, at the interface between the illuminating sources and the cool atmosphere, it is possible to write:

$$\Phi_{12}^{\text{out}} + \Phi_{13}^{\text{out}} = |\Phi_{12}^{\text{in}} + \Phi_{13}^{\text{in}}| \quad (5)$$

where “in” and “out” denote integration over directions towards and from, respectively, the atmosphere. In other words, all the photons incident on the atmosphere are eventually “scattered” back, possibly degraded to longer wavelengths.

This approach can be generalized to the resonance lines of He II, for which the relevant coronal photoionizing radiation is below 228 Å. We therefore have:

$$\Phi^{\text{res}}(\text{He II}) < \Phi^{\text{cor}}(\lambda < 228 \text{ Å}) \quad (6)$$

In this equation, Φ^{res} denotes the emerging photon flux in the resonance lines and continua of He II, and Φ^{cor} is the incident photon flux of coronal origin below 228 Å, the photoionization threshold for He I. The inequality in this equation arises mainly from photon loss processes involving absorption of resonance photons (mainly the He II 304 Å line) by other species, such as H I (continuum absorption threshold at 911 Å) and especially He I (threshold at 504 Å).

Taking into account the entire He I and He II system would give the following inequality:

$$\Phi^{\text{res}}(\text{He I}) + \Phi^{\text{res}}(\text{He II}) < \Phi^{\text{cor}}(\lambda < 504 \text{ Å}) \quad (7)$$

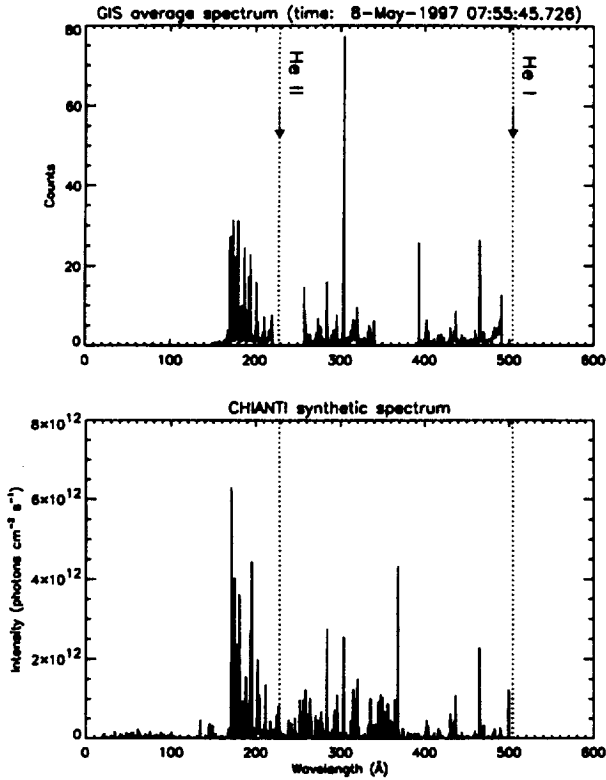


Figure 2. Average GIS spectrum of the quiet Sun (upper panel) and corresponding CHIANTI synthetic spectrum (lower panel). The dotted lines mark the photoionization thresholds of He I and He II.

In this case, however, the coupled radiative transfer-statistical equilibrium equations become considerably more complex. Moreover, the presence of a metastable level in the He I atom (level $1s2s^3S$), introduces significant collisional excitation or de-excitation processes in the rate equations. Nevertheless, since collisional effects and absorption by H I would tend to decrease the flux $\Phi^{\text{res}}(\text{He I}) + \Phi^{\text{res}}(\text{He II})$, we can still use inequality 7 for a first estimate of the importance of the PR mechanism in the excitation of the resonance He I and He II spectrum.

On the other hand, in equation 5 and its generalizations, inequalities 6 and 7, the geometry of the problem is not very important. The only stringent requirement is that the atmosphere is deep and cool enough to re-emit all the photons outwards.

3. THE OBSERVATIONS

With the EUV instrument of SOHO, and in particular with CDS, it is now becoming possible to test the PR mechanism directly, with the method described above. The goal is to compare observed fluxes in the main resonance He I and He II lines with the observed photoionizing flux from all the coronal lines in the relevant range. If the inequalities 6 or 7 are violated, then it can be inferred that the PR mechanism

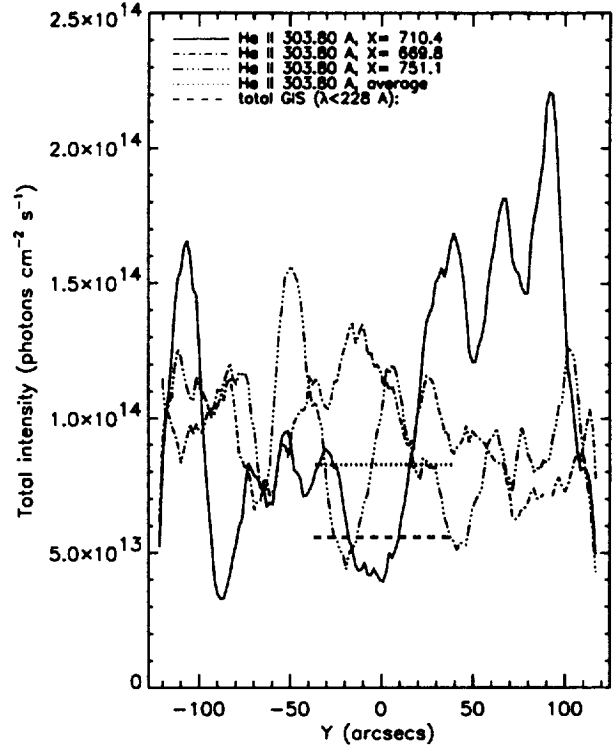


Figure 3. Comparison between EUV coronal photon flux and the He II Lyman- α along a cross-section of the CDS rasters shown in Figure 1. The average value for the He II line intensity refers to the area covered by the GIS FOV.

does not play a dominant role in the formation of the resonance helium spectrum. Clearly, accurate intensity calibrations are necessary, but the advantage of this method is that it does not require detailed radiative transfer calculations. Such calculations will be however required if the observations indicate that inequalities 6 or 7 might be valid, and therefore that the PR mechanism could be an important process to take into account.

We have analyzed CDS observations taken on May 1997. Both the Normal and Grazing Incidence Spectrographs (NIS and GIS, respectively) of CDS were used. An example of CDS/NIS data is shown in Figure 1, together with the field of view of the GIS spectra. A contour representation of the intensity of the Fe XV $\lambda 284$ line is overlaid on the He I map.

Work on a new intensity calibration of CDS GIS and NIS data is in progress (Del Zanna et al. 1999). We have applied to these data a preliminary version of that calibration. This intensity calibration has been derived from the comparison between line intensities observed in a very large number of CDS observations and theoretical calculations from the CHIANTI database (Dere et al. 1999; Landi et al. 1999).

An average GIS spectrum in the range of interest (0-504 Å) is shown in Figure 2, along with a synthetic spectrum derived by a Differential Emission Measure (DEM) analysis of the data. We have used this synthetic spectrum to estimate the photon flux in those

4. CONCLUSIONS

This is just the preliminary stage of a work that involves a careful cross-calibration of CDS/NIS and GIS. Once the new intensity calibration for the CDS detectors is ready, we plan to extend the analysis to the rest of that data series, taken at different positions on the solar disk (among other things, that will help taking into account limb variations on the observed intensities). Finally, detailed radiative transfer calculations will be useful in putting more stringent constraints than those in inequalities (6) and (7).

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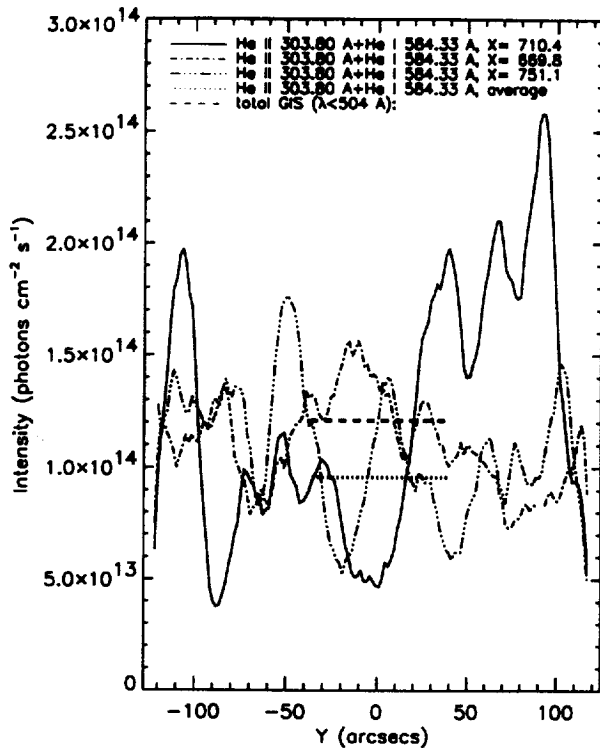


Figure 4. Comparison between EUV coronal photon flux and the main resonance lines of HeI and HeII.

spectral regions not covered by the CDS instruments.

In order to estimate Φ^{cor} , we have removed all the helium lines and continua in the calculation of the synthetic spectrum. This explains the conspicuous absence of the He II $\lambda 304$ line in the lower panel. Also, edge effects on the GIS detector produce spurious features which, at this compressed wavelength scale, appear like spectral lines (for example the “line” at ≈ 400 Å).

If we compare the He II $\lambda 304$ line intensity with $\Phi^{\text{cor}}(\lambda < 228$ Å), according to inequality (6) (Figure 3), we obtain that this line alone has about 50% more photons than available from all the coronal lines below 228 Å. This result seems to be independent of the particular calibration used.

On the other hand, if we extend the test by adding the He I 584 Å, the two lines together account for only about 80% of the photons in all the coronal lines below 504 Å (inequality 7), and thus the result is less conclusive, at least with this preliminary instrumental calibration (Figure 4). However, we recall that collisional effects and absorption by hydrogen could significantly alter the balance. And, of course, we should add at least the resonance continua to the number of photons emitted by helium (in the case of He I, the recombination continuum accounts for about half $\Phi^{\text{res}}(\text{He I})$). Clearly, in this case more stringent upper limit than those given by inequality 7 are required, via detailed radiative transfer calculations.